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Diagnostic Systems as Basis for Technological Improvement

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Abstract

Hereunder the ways of technical diagnostics in metal manufacturing and peculiarities of challenges which are faced in technical diagnostics are given. The matters of the ways of technical diagnostics, which are required to be solved in near future, are described in the article. Solutions of problems concerning diagnostics of condition of an edge tool, using real-time vibration analysis, are provided. The article says about affect of bearings of spindle units on three-dimensional distribution of vibration parameters. An example concerning a spindle unit that induces auto vibration, which produce a false diagnosis regarding the condition of the edge tool, is given.

Keywords: diagnostic systems, cutting process, tool, vibroacoustic signal.

1. Introduction

Machine tool methods of technical diagnostics emerged in the 80s. Flexible manufacturing systems and modules, were produced exactly at that time. Since, the instrument base of technical diagnostics systems has fundamentally changed; the capacity of computers increased, that is, diagnostic algorithms were used, its speed and memory capacity increased much; portability and reliability of all modules of diagnostic systems were improved, technical capabilities of transducers were much increased. However, the technological equipment underwent significant changes. Automated technological systems of machining were improved i.e. different manufacturing operations were concentrated at a single workplace. The goals to process details with exact accuracy were put on agenda. Manufacturing of new materials was in demand. Along with mentioned issues other goals occurred. Statistical data on failures of technological systems, defined by an unplanned deterioration and breakage of cutting tools in the process of different treatment types, indicates that the downtime of equipment with NC due to such failure is up to 50% of the time shift. Under the same conditions downtime caused by hardware failures does not exceed 6% of the working time [1, 2, 3].

2. Tasks Completed by Diagnostics Systems and Current Problems

As an instrument of obtaining diagnostic information in modern machine tools one can identify three areas of diagnostic systems that are notable for fields of application and frequency. This is operational (OD), test (TD) and research diagnostics (RD). OD is oriented to the status track of important nodes and processes on the machine in real-time; TD involves periodically obtaining information about the major components and changes in the settings. RD is designed to understand the physical processes that determine the relationship of the functional parameters of the technological equipment and processes for diagnostic parameters that then are used in OP and TD. On the basis of RD effective diagnostic parameters are identified and rational algorithms for exposing different types of failures in test mode and real-time, as cutting tools and equipment units, are constructed. The mentioned areas of

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diagnostics are closely intertwined, defining each other's range of unsolved problems and priorities.

OP is the direction in which it's significance increases sharply with the expansion of work on the development of automated technological systems. OD tasks include such key areas as diagnostics of the cutting process, the state of the cutting tool and the most important junctions, size control and correction of cutting tools state, certification of the technological process, which consists of writing accompanying the operation diagnostic parameters, and a number of other problems that arise in specific conditions. As the adoption of "unmanned technology" is impossible without equipment intellectualization, the most important stage of OD is to upgrade machines with integrated sources of information about the most important junction state and quality of the technological process flow. Many works cover these issues and offer a variety of approaches to solving them [1-6, 9, 11-13].

The task of recognition and fixing breakdowns and maximum cutting-tool wear (CTW) should be singled out of the listed OD issues. At present time, while the creation of OD systems one focuses on the power loading control and vibroacoustic (VA) signals in the cutting zone generated during the product processing. Modern drive gears provide a signal input to NC system of machine tool which is proportional to the generated torque moment. If the rotational moment that occurs during cutting, can be distinguished on the signal background determined by the idle run of the machine, then with its help one can observe CTW. Practice shows that it is not always possible to watch with such a system over the small point tool wearing and finish tool, because the increment of power generated by such an instrument, usually is very small, and it is difficult to distinguish it against the background of the idle time. Therefore, to control small finish tool wearing and breaking the number of monitored parameters in the cutting process is extended by controlling VA signal parameters [3]. The nature of power and vibration parameters is different, therefore, despite the fact that they sometimes correlate with each other, parallel control of power and VA parameter has a positive effect, allowing identifying a larger percentage of the worn tool, not bringing the situation to a breakdown. The disadvantage of the algorithms used to control the wear and breakdown of tools is the need for prior training to obtain information about the level of diagnostic parameters in the process of edge tool working. Even after receiving this information there is an issue of limiting curves designation in the range of which the changes of diagnostic parameters are valid. Good or bad operational results are determined for each machine tool individually. The position of the limiting curves and its width can be transformed along with the change of cutting process, the requirements to the quality of an upper layer of the product, the rigidity of the work piece in the zone of cutting. In other words, the representation of permissible limits change of diagnostic parameters values may require preliminary studies involving the work of an engineer - technologist. The result of this study should be a number of factors that determine the boundaries of the limiting curves of monitored parameters. The need of limiting curves setting for a few controlled parameters makes the task particularly difficult [5]. The development of OD in terms of instrument diagnostics should go towards improving algorithm of recognition, as well as creating a system of automatic programming diagnostics, combined with the systems of automatic preparation of control programs. In the general formulation this problem is extremely complicated for a rigorous solution, especially when using VA settings, characterized by nonlinear dependence on the processing conditions. The task is simplified if it focuses on a specific production, wherein a limited set of products is processed automatically, repeated according to the production needs. In this case it is possible to classify the instruments into groups, where for each group is given a certain set of coefficients defining the boundaries of the limits with respect to the values obtained when using a new and sharp tool.

But even in this case there is the need of simplification, for example, exclusion of wear control in some areas of processing, characterized by the spread of controllable parameters because of the instability of the processing conditions. In other words, in this case, wear control is transferred to another sector of the work piece. sections with more stable conditions. In some cases, one will have to simplify the dependence of controlled parameters of the border on the coordinates of the workspace, using the constant limits for different parts of the process and different tools. However, there are problems concerned with the processing of single products with high demands on surface quality. In this case, one must have an ability to create control programs, combined with the diagnostic system, excluding the preliminary training. For such cases it is necessary to create databases to be taught in with the values of the permitted range of the controlled parameters for different processing conditions. The procedure for the creation of such a database is a complex independent task. This is due to the fact that, in general, in the database one should not only consider the modes of processing and work material, but also various dynamic characteristics of tools, blanks, and the most elastic system at different points of the workspace. There are some complications in the number of characteristics to be described, for example work piece material and its dynamic characteristics, etc.

3. Examples of Diagnostics Problems Solutions

Creation of the computer-aided manufacturing operational diagnostics programming system can be facilitated by seeking and utilization of such parameters of vibrating signals which do not only depend on variations of conditions of manufacturing but constantly react upon a state change of cutting edges of tools. These are usually the dimensionless parameters that are obtained by dividing one characteristic of the controlled signal by the other. To detect incipient defects can be applied such parameters as crest factor, kurtosis signal, but as the experience has shown they are used in the analysis of incipient defects and under the condition that it is not a smooth cut [5, 7]. For example, Figure 1 shows the change in ratio of effective amplitude VA signal, taken in different frequency bands. As a high-frequency range was taken the range of 7100-7800 Hz and as low-frequency range was taken the range of 900 - 1200 Hz. It is shown that the ratio of the effective amplitudes (A_{hf}/A_{lf}) in these bands decreases along with increasing tool wear on the back edge for all cutting speeds obtained during front turning. It is seen that in the range of 30-50 m/min, it decreases up to 50%. At low cutting speeds in front turning pulses occurred in VA signal (examples are shown on the fig. 1), which led to an increase in the amplitude ratio. For such an amplitude ratio as a diagnostic parameter, one must know in advance the rules for frequency band selection and to investigate its behavior in a broader change in processing conditions.

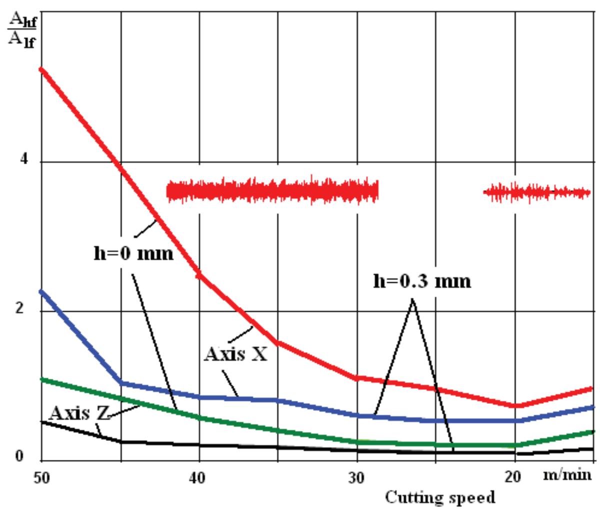


Fig. 1. The change of relation between amplitudes of VA signals and run-out increasing under different velocities of cutting (the examples of VA signals for different velocities are shown).

Besides tools, operational diagnostics systems should endorse other mechanisms, whose maladjustment and run-out need a sort of control by an operator. Along with a spindle block, tool and raw stock swap mechanisms as well as some guard mechanisms are also included. Much depends on particular design and technical incomplete works and often the decision to implement operative diagnostics is taken after a technological complex was put into service. The research unveiled [5] that availability of dimensional audit and correction system allows to eliminate more than 60% of failures as related to products parameters. The scope of functions of the operational diagnostics usually gets wider when a particular task is fulfilled.

Test diagnostics (TD) can base itself on OD means, mobile diagnostics complexes as well as stationary ones, which are assigned to testing units of machines. The production practices of flexible automated manufacturing system (FAM) demonstrated that failure as related to products parameters which are linked to misalignment of different mechanisms, are able to drastically decrease the operational efficiency of FAM systems [1, 2]. The misalignment of an element of the mechanism can lead to accelerated wear of other elements which are related to the element. Based on the results of TD, the need of maintenance, adjustment, change of a unit should be determined. The example of effect of TD quality towards probability of a false diagnostics when OD has been applied is given below.

Putting the TNL-100AL numerical control lathe in service, operators face a problem of intensive self-oscillation when changing to a mode, for instance when slotting the grooves (fig. 2).

The frequency of auto-oscillations was about 5.9 kHz. Taking into account so high frequencies which are common to cutting machines, a grooving tool was named as a reason of the fault. The further investigation was initiated due to the fact that the same grooving tool at another lathe showed fairly acceptable results. The draft of amplitude frequency characteristics for both lathes (fig.2) showed that the first eigen frequency of faulty lathe number 1 was less than on lathe number 2 at 109 Hz and dynamic compliance is more than 70%. Logarithmic decrement of oscillation was 0.057 and 0.154 for lathes #1 and #2 accordingly. However, the relation between self exited oscillations under high frequencies and dynamic characteristics of the spindle failed to be established. Comparison of experimental amplitude frequency characteristics, obtained impulse force impact on the spindle [10], and amplitude frequency characteristics, obtained by mathematical modeling [1, 8] revealed that the variation of amplitude frequency characteristics corresponds to the stress state at the front bearing. A stage of RD was started with a parallel recording of VA signals of the self exited oscillation process from the body of the spindle carrier and tooling unit. There is a profile of the recorded VA signals in fig. 3. The upper diagram shows VA signals on the spindle carrier body and the lower one shows VA signals on a capstan turret. One can see that the outlines of the recorded signals are detailed in mane details.

The outline of VA signal in fig. 3 does not have strictly periodic character. Its spectral decomposition shows that there are spectral maxima at 63, 82, 102, 122 Hz in a spectrum for both enveloping signals. It could be noted that a phase of minimum in a signal at the spindle carrier appears .002 sec earlier.The above-listed FRQs are much lower than eigen frequencies of spindle, cutting tool and other elements of the lathe. This fact gives ground to suppose that the modulate low-frequency oscillations are considered to stem from self excitation, the nature of which is given in fig. 4.

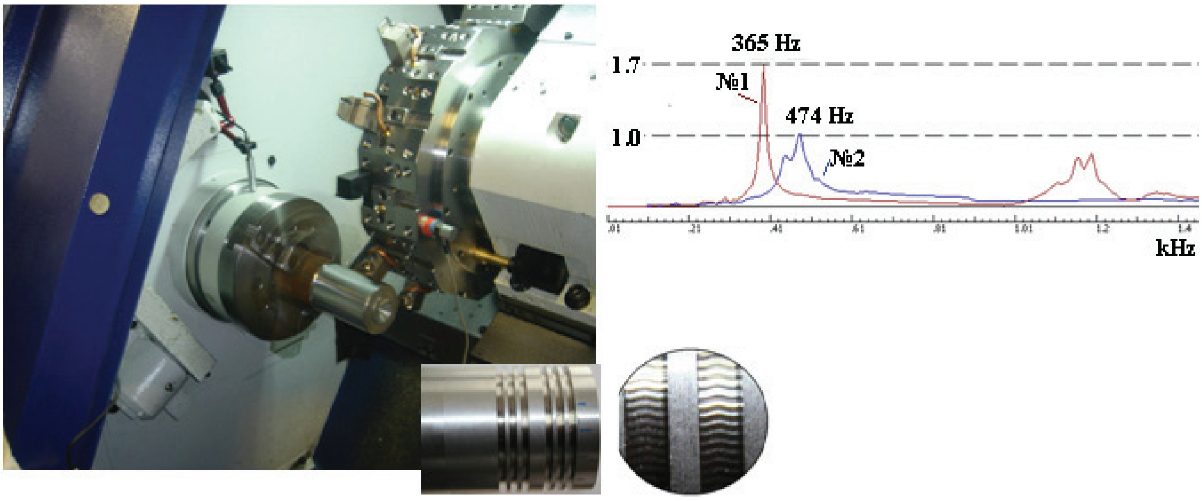
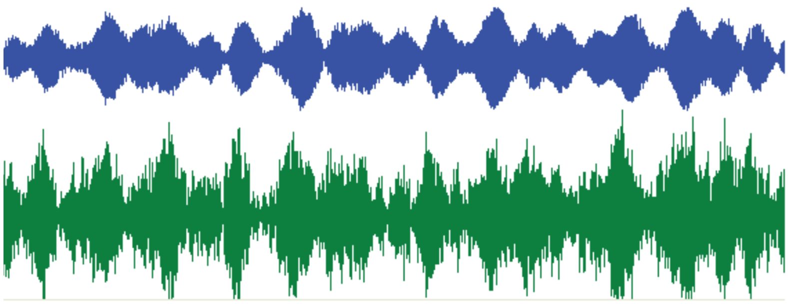


Fig. 2. Picture of the traces of vibration, amplitude frequency characteristics of spindles of two samples of lathes TNL-100AL



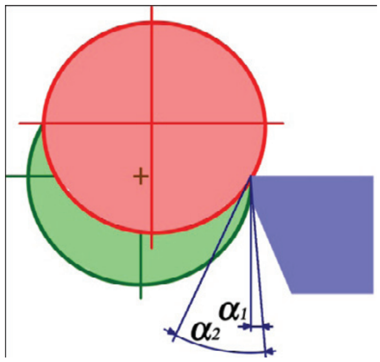


Fig. 3. Profile of VA signals recorded on the capstan turret (upper diagram) and spindle carrier. Recording period 0.2 sec.

Fig. 4. A scheme of deviation of the centre of a work piece and the given angel under auto-oscillations.

It schematically shows that due to decreasing of radial interference the spindle with the work piece is able to hover over a cutting edge and “rebound” it under action of the cutting force. Herewith, the real given angle is increased, the damping effect is decreased. In the process of further cutting the spindle with the working piece gradually goes down to initial position by small leaps when each element of a cutting chip is formed. When the spindle was down, the high-frequency oscillations are faded for a short time, but the process of moving of the spindle is repeated once again. The situation resembles the way of playing the violin, when a bow slides over the strings. Here the cutter acts as a string (due to the fact that oscillations take place at the frequency of the cutter); the spindle and working piece act as a bow, controlled by low-frequency self exciting oscillation process. Finally, the decision to change the spindle unit was taken.

Problems of TD appear at the stage of manufacturing of lathe units, procurement of equipment and at service. For instance, when spindle units are manufactured, the accuracy of rotation and heating-up in supports are checked. The feature of emerging faults is that they do not impact immediately on functional characteristics of units. Incipient defect in a period of time will enlarge up to significant problem that impedes a normal operation of the unit.

At the beginning the accuracy and quality of the surface are deranged, the further service may lead to a functional failure, which causes outage. So, the methods of TD should include checks, allowing determine incipient defects in units. For instance methods of VA diagnostics have high-level sensitivity towards modification of conditions of inter-engagement between moving elements of units. To choose more sensitive parameters towards modifications of quality in the controlled units, the research should be conducted which allows to set physical factors, which in their turn bind incipient defects with diagnostics parameters.

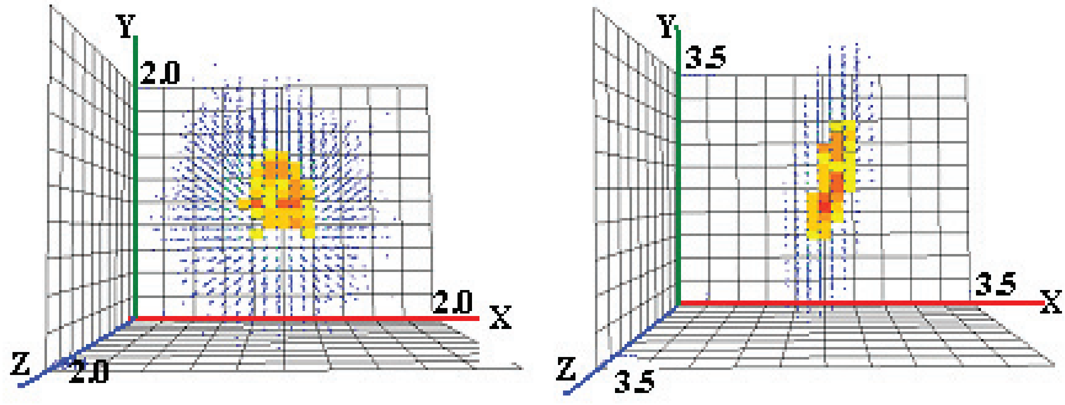


Fig. 5. Examples of modeling of space distribution of vibrations for grinding wheel spindles (axis X is the axis of the spindle). The colors designate different levels of oscillation strength

For VA signals it can be correlation and spectrum analysis, envelope analysis in different frequency bands, statistic analysis. Also here can be mentioned the analysis of space distribution of VA signals ("rose of vibration" analysis). Every point of elastic system executes dimensional oscillations. The pointing of dominated directions of oscillations in different frequency bands also bears useful information on reasons of faults emerging. As an example, dimensional "rose of vibrations" within the octave band 2.8-5.6 kHz for front supports of grinding wheel spindle [8] is given on fig. 5. Both spindles in terms of the heating temperature and accuracy of rotating meet the current normative standards, despite the second spindle had heating temperature higher by 15^0. Apparently, the 2^{nd} spindle is characterized by more clear asymmetry of "rose of vibration" and by wider spread of distribution of oscillations. The same problem exists for other factors. There are variations in a unit, but to rationally solve dichotomy fit/not fit without keeping an eye on the unit during its service is very complicated. For this purpose the correlation between results of TD and results of monitoring the unit during its service should be intensified.

4. Summary

The development of effective systems of operational diagnostics is possible in case of aiming of all up-to-date capabilities of science at research of physical meaning of those physical phenomena which excite negative situations. These situations occur when technological equipment is in service. The great attention should be paid at expansion of utilization of vibroacoustic signals as these signals carry information both on cutting process and friction.

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